On-line fringe tracking and prediction at IOTA

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Abstract

The Infrared/Optical Telescope Array (IOTA) is a multi-aperture Michelson interferometer located on Mt. Hopkins near Tucson, Arizona. To enable viewing of fainter targets, an on-line fringe tracking system is presently under development at NASA Ames Research Center. The system has been developed off-line using actual data from IOTA, and is presently undergoing on-line implementation at IOTA. The system has two parts: (1) a fringe tracking system that identifies the center of a fringe packet by fitting a parametric model to the data; and (2) a fringe packet motion prediction system that uses characteristics of past fringe packets to predict fringe packet motion. Combined, this information will be used to optimize on-line the scanning trajectory, resulting in improved visibility of faint targets. Fringe packet identification is highly accurate and robust (99% of the 4000 fringe packets were identified correctly, the remaining 1% were either out of the scan range or too noisy to be seen) and is performed in 30-90 milliseconds (depending on desired accuracy) on a Pentium II-based computer. Fringe packet prediction, currently performed using an adaptive linear predictor, delivers a 10% improvement over the baseline of predicting no motion.

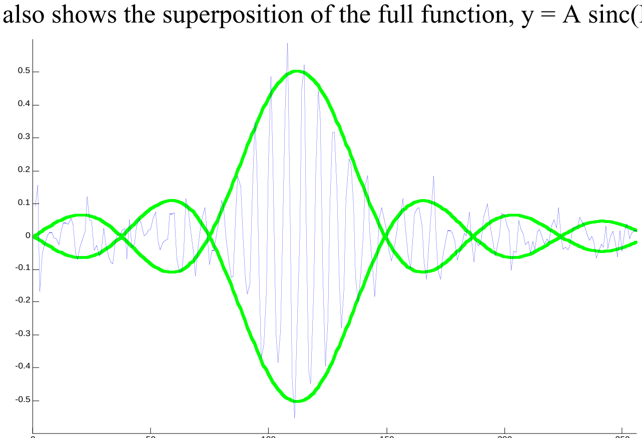
Fringe packet identification

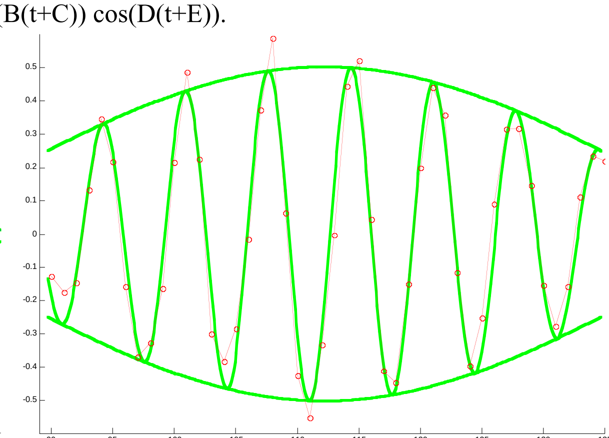
To enable on-line tracking and prediction, the first step is to autonomously identify the center of a fringe packet. The approach taken here was to fit the raw data (after some simple filtering) to a parametric model representing a distortion-free fringe packet. The parametric model chosen was:

$$y = A\ \mathrm{sinc}(B(t+C))\cos(D(t+E))$$

where y is the normalized value from the interferometer ((channelA-channelB)/(channelA+channelB)), t is time, shown on the horizontal axis on the plot below. This particular grouping of parameters (e.g., D(t+E) instead of Dt + E) was chosen to facilitate gradient-based optimization of the functional parameters. A combination of linear regression, gradient-based optimization, and fast Fourier transform (FFT) tools were used in designing the parameter identification algorithm. The center of the fringe packet is represented by parameter C, and is the only one needed for simple fringe tracking. For prediction of fringe motion (and possible extensions, including on-line data reduction), all 5 parameters are useful.

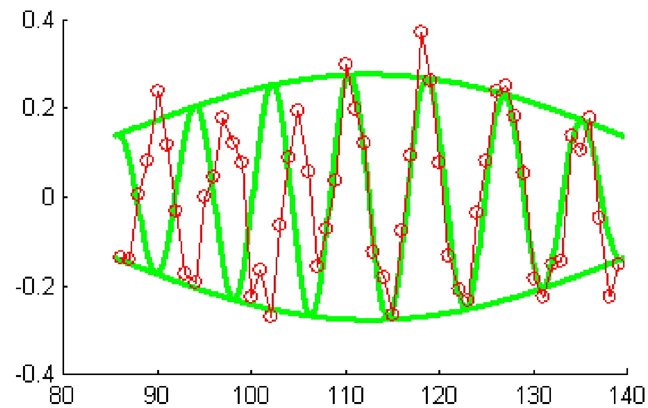
Fringe packet parameters were identified on the 4000-scan data set from IOTA to an accuracy as good as can be determined by eye. That is, we can find fringe packet parameters (amplitude, spread of sinc function, center, frequency of fringes, and phase shift of fringes) that appear to be the best match to the actual data. The fringe packet identification algorithm is discussed later. Shown in these figures is an example of fitting to some data from IOTA. The plot on the left shows superposition of $y = \pm A\ \mathrm{sinc}(B(t+C))$ with the actual data (data is discrete - one scan contains 256 points, but points have been connected to improve data visualization). In addition to this, the plot on the right is zoomed in on the packet center and also shows the superposition of the full function, $y = A\ \mathrm{sinc}(B(t+C))\cos(D(t+E))$.





Summary of the steps in identification:
1) Data sets from each of the two collectors are combined: y=(channelA-channelB)/(channelA+channelB)
2) Outliers and local bias are removed
3) The envelope of the absolute value of the signal is calculated, eliminating the individual fringes. Ideally this function would be y = A abs(sinc(B(t+C)))
4) An estimate for the center of the fringe packet (C) is found by maximizing weighted symmetry over the envelope.
5) Using an initial guess for B, the remaining parameter A is found by a least squares fit to the data.
6) Now that A, B, and C have good initial estimates, a gradient-based optimization is performed to find A, B, and C that form the least squares fit to the data.
7) The fringe parameters, D and E, are found by fitting the ideal fringe function to the data over the center of the fringe packet (half height of the sinc function determines the center region).
8) An FFT provides an initial guess for D and E, and a gradient-based optimization finds C, D and E, with A and B held fixed.

Simultaneous gradient-based optimization of A, B, C, D, and E was tried, but did not work as well on the noisy data as the sequential procedure listed above. One example of a reason for this difficulty can be seen in the accompanying figure. Half-way through the fringe-packet scan, a sudden phase shift was encountered. If all 5 parameters were adapted simultaneously, the result would be a flat line, with A=0, since the identification would be unable to lock onto the left and right halves of the fringe packet. Squared error would be minimized approximately by a flat line, A = 0. With the present algorithm, two parameters representing the sinc function envelope (A and B) were held fixed while the fringe frequency and phase shift (D and E) were identified. The identification locked onto the right half of the fringe packet since that resulted in a better fit than the left half.



Simulation of the effect of atmospheric turbulence on the optical path difference was pursued to enable development of simulated fringe packet data. With simulated data, it will be possible to quantify the accuracy of the fringe packet identification, and possibly refine the identification algorithms.

Prediction of fringe-packet-center motion

Initial experiments with fringe packet motion prediction were performed. An adaptive linear model using present and past identified fringe parameters was developed as a first step. The center of the next fringe packet and the magnitude of fringe-packet-center motion were predicted, with the goal of optimizing on-line the parameters (e.g., travel limits and rate) of the next scan. This model produced approximately 10% improvement over no prediction (i.e., predicting that the fringe packet would remain where it was on the next scan). Extension to nonlinear prediction methods, including neural networks is under investigation.

Summary and future research

On-line fringe tracking and identification algorithms have been developed based on off-line data from the IOTA interferometer. Autonomous identification of fringe packet centers, even in the presence of poor signal-to-noise ratio, has been demonstrated using algorithms that can run fast enough to enable real-time implementation (30-90 milliseconds on a Pentium II-based computer). Some encouraging results on fringe-packet motion prediction have been obtained using an adaptive linear predictor.

Major areas of future work include implementing these algorithms on the IOTA interferometer (presently underway) and extending the fringe packet prediction algorithm to a nonlinear neural network.